Regional and seasonal differences in aerosol radiative forcing over India and adjoining oceanic regions

A THESIS

submitted for the Award of Ph. D. degree of

MOHANLAL SUKHADIA UNIVERSITY

in the

Faculty of Science

by

Sumita Kedia

Under the Supervision of

Dr. S. Ramachandran

Associate Professor
Space and Atmospheric Sciences Division
Physical Research Laboratory, Ahmedabad, India.

DEPARTMENT OF PHYSICS

MOHANLAL SUKHADIA UNIVERSITY

UDAIPUR

2010

CERTIFICATE

I feel great pleasure in certifying the thesis entitled "**Regional and seasonal differences in aerosol radiative forcing over India and adjoining oceanic regions**" by Sumita Kedia under my guidance. She has completed the following requirements as per Ph.D. regulations of the University

(a) Course work as per the university rules.

(b) Residential requirements of the university.

(c) Presented her work in the departmental committee.

(d) Published/accepted minimum of one research paper in a referred research journal,

I am satisfied with the analysis of data, interpretation of results and conclusions drawn.

I recommend the submission of thesis.

Date: 2010

Dr. S. Ramachandran
(Supervisor)
Physical Research Laboratory
Ahmedabad, India.

Countersigned by
Head of the Department

DECLARATION

*I Ms Sumita Kedia, D/o Mr. Bishwanath Kedia, resident of A-4, PRL residences, Navrangpura, Ahmedabad - 380009, hereby declare that the research work incorporated in the present thesis entitled "***Regional and seasonal differences in aerosol radiative forcing over India and adjoining oceanic regions***" is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required. I solely own the responsibility for the originality of the entire content.*

Date:

Sumita Kedia

(Author)

Dedicated To my

Parents

Acknowledgements

Considerable efforts have been taken to bring the thesis to the current form. It is a great pleasure to thank all who gave their support with dedicated spirit and have been part of my life as teachers, friends, colleagues and family members.

First and foremost, I express my honest gratitude to Dr. S. Ramachandran under whose guidance the work has been carried out. I thank him for his continuous support, inspiration, encouragement and motivation during this entire work period. His guidance helped me throughout my research and writing of this thesis. The sublime blend of freedom and supervision provided by him made the thesis work thoroughly enjoyable. I could not have imagined having a better advisor and mentor for me for my Ph.D study.

I am also thankful to Prof A. Jayaraman for his concern towards me and about the progress of my work. I express my sincere thanks to T. A. Rajesh for his help and support throughout the period. I thank him for maintaining various instruments in the laboratory.

I thank Prof. J. N. Goswami, Director, Physical Research Laboratory, for providing me all the necessary facilities to carry out my thesis work.

I would like to thank Prof. Rajesh Pandey, Physics Department and the Ph. D. section of Mohanlal Sukhadia University for their kind co-operation throughout my thesis.

I am very much indebted to Profs. A. K. Singhvi, Shyam Lal, R. Sekar, S. A. Haider, U. Sarkar, R. Ramesh, M. M. Sarin, P. K. Panigrahi, J. Banerji and Drs. B. Bapat, K. P. Subramanian, Pallamraju, Varun Sheel, H. Mishra, S. Mohanty, D. Angom, and R. P. Singh for encouragement at various stages of my research.

I would like to thank Acharya sir and Modh sir for solving the problems related to sun photometer. Thanks to Sunil bhai, Venkataramani sir, Dipu da, Som Sharma, Sudheer, Rengarajan, Ravi bhushan and Navin Juyal for their support on various occasions.

I thank Dr. P. Sharma and for his help and care during course work at PRL. I also thank Dr. Bhushit for advice and help during reviews at PRL and Ph.D. registration at Udaipur.

I am grateful to Prof. Swapna Mohapatra (Utkal University), who is a great inspiration for me. She has contributed a lot through her care, personal guidance and encouragement.

I wish to express my sincere thanks to Drs. C. B. S. Dutt (ISRO HQS., Bengaluru), R. Sridharan, K. Krishna Moorthy and Suresh Babu (SPL, VSSC, Trivandrum) for giving me the opportunity to participate in the ICARB 2006 and WICARB 2009 cruises, and for their support and encouragement. I am also thankful to ISRO-GBP for funding support during campaigns. I thank my friends Spandana (Andhra University), Shailesh (NRSC), Sumit (IITM), Shilpa and Reachal (Goa University), and Liji (SPL) for making the cruises memorable.

I acknowledge NOAA Air Resources Laboratory, USA for the HYSPLIT model and NOAACIRES Climate Diagnostic Center, USA for providing NCEP reanalysis data. MODIS and MISR AODs, and TOMS ozone used in the study are downloaded from the GES-DISC, NASA. Rainfall data are obtained from NOAA, NESDIS National Climatic Data Center, USA. I am grateful to the National Centre for Antarctic and Ocean Research (NCAOR) and the Department of Ocean Development (Ministry of Earth Sciences) for giving me an opportunity to sail and conduct measurements on board Sagar Kanya. I thank Drs. B. N. Holben and S.N. Tripathi for their efforts in establishing and maintaining the AERONET sun/sky radiometer at Gandhi College and Kanpur the data of which are used in the present study.

I cannot forget to thank my friends Ribu (IITB) and Madhav (Andhra University) who were always ready to help me everytime I needed. Thanks are due to both of them for helping me in improving my computational skills. I also thank to Rajesh (ARIES) for making my participation in the SOLAS 2007 fruitful and enjoyable.

I am thankful to Dr. Ramya with whom I have spent a good time at PRL. My special thanks to my junior Rohit for his help, support and cooperation during the course of this thesis.

I wish to thank my seniors Drs. H. Gadhavi, D. Ganguly, N. Rastogi, L. Sahu, S. K. Rai, Y. C. Nagar, A. S. Maurya for their concern and help. Thanks to Amit, Satya, Subimal, Shreyash, Rohit, Sanat, Uma, Ritesh and Rajesh who helped me

in various ways and gave me valuable suggestions during this period.

I would like to thank all the members of the Computer center, especially Jigar bhai, Tejas, Alok, Mishra Ji for the help in computer related problems. The help from Uma madam, Nishtha madam, Pragya, Alam, and all the supporting staff of PRL library are thankfully acknowledged. Thanks to Parul madam, Priti madam, Pauline, Nandini madam, Jayashree, Ranganathan, R. S. Gupta, Ghanshyam Bhai, Senthil Babu and Sivadasan for their help in various stages.

I was lucky to enjoy the cheerful friendship of many people at PRL. Arvind, Anil, Gyana, Alok, Kirpa, Vishal, Bhavik, Rahman, Sanjeev, Ramji, Manan, Harinder, Lokesh, Shuchita, Sumanta and Timmy for making me feel at home. I feel great that I have a friend like Ashwini. I have spent a memorable time in his company onboard cruises, at Mount Abu and obviously in PRL. I would also like to thank my friends Pradeep, Sumit, Surya, Rashmi, Annu, Bharat and Ananta for their care and support.

I wish to thank my juniors Iman, Chinmay, Arvind Saxena, Kabitri, Amzad, Fazlul, Srinivas, Prashant, Neeraj, Vimal, Patra, Bhaswar, Jayati, Suratna, Yogita, Moumita and many others have helped me in several ways in the course of my Ph.D.

I cannot finish without saying how grateful I am to my parents, for their care, concern, blessing and love. I thank them for allowing me to get everything I wanted in my life. I am grateful to my didi and jiju for their continued support. My brother Sunil and my sister Monika are a source of happiness and refreshment for me. I am extremely indebted to my in laws for their love and support.

I was lucky enough to get my soul-mate Naveen (my husband) during the course of Ph.D. in PRL. I owe my loving thanks to him for his care, affection, love and support. He has contributed in enormous amount during the entire period in making my life happy. I have found him standing with me always when I required. Without his support, it would have been impossible for me to finish this work.

Sumita Kedia

Abstract

The concept of aerosol radiative forcing (ARF) is used to quantify the strength of aerosols from both natural and anthropogenic sources in causing climate change. The work is motivated from the rising concern for global climate change and the existing uncertainty in the current understanding due to the incomplete knowledge of aerosol optical and radiative properties, and their regional variations. The goal of present work is to study the optical, physical and radiative properties of aerosols including ARF, and their spatial and temporal variabilities over different environments in the Indian subcontinent and adjoining oceanic regions. The study locations in India include, Ahmedabad (urban, industrialized location), Gurushikhar (high altitude, remote site), Kanpur (urban, industrialized location over the Indo-Gangetic plain) and Gandhi College (rural site over the Indo-Gangetic plain). The oceanic regions include the Bay of Bengal and the Arabian Sea where the study has been carried out.

A large spatial and temporal variation in aerosol optical depth (AOD) is observed over both continental and marine environments. AODs over Ahmedabad and Gurushikhar showed winter low and summer or premonsoon high, while in Kanpur and Gandhi College winter AODs are found to be higher. AODs are found to be about 1.4 times higher over the Bay of Bengal (0.36) when compared to that over the Arabian Sea (0.25). Spectral distribution of AODs are further analyzed to obtain some crucial information on the physical and optical characteristics of aerosols by deriving the second derivative of spectral AOD ($\alpha^{'}$). The analysis revealed the dominance of wide range of fine mode fractions or mixture of modes during winter over Ahmedabad, Kanpur and Gandhi College; while coarse mode aerosols dominate over Gurushikhar. Over the marine environments, AOD spectra over the Bay of Bengal were predominantly made up of a mixture of fine modes while the Arabian Sea had more coarse mode particles during the study period.

The clear sky shortwave ARF and heating rate is estimated over all the study locations/regions and discussed. A large spatial and seasonal variability is observed in the ARF over all the study locations in India. The ARF values are found to be

highly sensitive to the single scattering albedo. Atmospheric forcing is found to be in the range of 12.3-54.0, 4.3-8.9, 20.8-36.2 and 22.2-34.2 Wm^{-2} over Ahmedabad, Gurushikhar, Kanpur and Gandhi College respectively during different seasons. Over the Bay of Bengal, the ARF is found to be higher than the forcing obtained over the Arabian Sea. The average atmospheric heating rate over Bay of Bengal is found to be $\sim$0.3 K/d, which is a factor of 2 higher than that over Arabian Sea. A sensitivity analysis revealed that (1) the curvature effect in AOD spectra has insignificant impact in modifying the ARF and heating rate, and (2) the net Earth-atmosphere energy content shows minor differences when aerosol vertical profiles are used for the estimation of forcing. The present study aims to improve the knowledge about the spatiotemporal variability and radiative effects of aerosols over the Indian landmass and the adjoining oceanic regions which will help in reducing the uncertainty in aerosol radiative forcing and its future projection on climate.

Key words: Aerosol optical depth, Spectral variabilities, Radiative forcing, Heating rates, Single scattering albedo, Vertical profile

Contents